REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1996.

3. REPORT TYPE AND DATES COVERED
Master's Thesis, Engineer's Thesis

4. TITLE AND SUBTITLE STUDIES ON SUBMARINE CONTROL FOR PERISCOPE DEPTH OPERATIONS

5. FUNDING NUMBERS

6. AUTHOR(S) TOLLIVER, John V.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITOR ING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

Requirements for submarine periscope depth operations have been increased by integration with carrier battle groups, littoral operations, and contributions to joint surveillance. Improved periscope depth performance is therefore imperative. Submarine control personnel rely on a large number of analog gauges and indications. An integrated digital display system could enhance the ergonomics of the human control interface and display
additional parameters. This thesis investigates the required feedbacks for robust automatic depth control at periscope depth, and th indirectly determines the additional parameters desired for an integrated display.

A model of vertical plane submarine dynamics is coupled with first and second order wave force solutions for a particular submarine hull form. Sliding mode control and several schemes of state feedback are used for automatic control. Head and beam seas at sea states three and four are investigated. The automatic control effectiveness provides insight into the indications used by t ship's control party in operations at periscope depth. One possible display system is proposed, with several additional enhancemen to improve ship's safety, reduce operator fatigue, and enable accurate reconstruction of the events leading to a loss of depth control

14. SUBJECT TERMS Submarine, periscope depth, control optimization, wave forces

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICA-TION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

Approved for public release; distribution is unlimited.

STUDIES ON SUBMARINE CONTROL
FOR PERISCOPE DEPTH OPERATIONS

John V. Tolliver
Lieutenant, United States Navy
B.S., Montana State University, 1988

Submitted in partial fulfillment
of the requirements for the degrees of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING
and
MECHANICAL ENGINEER

from the

NAVAL POSTGRADUATE SCHOOL
September 1996

Author: ______________________________
John V. Tolliver

Approved by: ______________________________
Fotis A. Papoulias, Thesis Advisor

____
Terry R. McNelley, Chairman
Department of Mechanical Engineering

ABSTRACT

Requirements for submarine periscope depth operations have been increased by integration with carrier battle groups, littoral operations, and contributions to joint surveillance. Improved periscope depth performance is therefore imperative. Submarine control personnel rely on a large number of analog gauges and indications. An integrated digital display system could enhance the ergonomics of the human control interface and display additional parameters. This thesis investigates the required feedbacks for robust automatic depth control at periscope depth, and thus indirectly determines the additional parameters desired for an integrated display.

A model of vertical plane submarine dynamics is coupled with first and second order wave force solutions for a particular submarine hull form. Sliding mode control and several schemes of state feedback are used for automatic control. Head and beam seas at sea states three and four are investigated. The automatic control effectiveness provides insight into the indications used by the ship's control party in operations at periscope depth. One possible display system is proposed, with several additional enhancements to improve ship's safety, reduce operator fatigue, and enable accurate reconstruction of the events leading to a loss of depth control.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I owe my deepest thanks to my wife Kelly and her parents Harvey and Janet for their support, and my children Jacob and Micaela for their love.

Special acknowledgment is due to Randy Dean of the Johns Hopkins Applied Physics Laboratory for his support in providing wave force solutions.

Finally, I owe deep appreciation to Professor Fotis Papoulias for his guidance during the course of this thesis.

INTRODUCTION

GENERAL

The need for attack submarines to operate at periscope depth has been increased by integration with carrier battle groups, operations in the shallow littoral, and contributions to joint surveillance.

Operating at periscope depth beneath a seaway, a submarine is in an unstable condition. As the free surface is approached, the seaway forces increase, trying to pull the submarine to the surface. To counter these forces, the ship's ballast is changed and control surfaces are used. Because of the seaway's stochastic nature, manual operation for long periods at periscope depth taxes the ship's control party.

Operators must remain aware of the environmental conditions. If the sea becomes quiescent, the submarine will sink out. If the sea suction forces are greater than the ballast and planes authority, the submarine will broach the free surface increasing detection risk by several orders of magnitude. Other events, like temperature or salinity changes, can also have major effects on reliable depth keeping. Contributing to the environmental issues, the need to use minimum speed for a given sea state to control the detectable mast feather reduces the available planes authority, and increases the difficulty of depth control.

However, the current submarine force is not optimized for these operations. One inexpensive area for improvement is the display system for the ship's control party. Modern digital display systems offer ergonomic improvements over current gauges and readouts.

Given a requirement to conduct submarine ship control manually, a fundamental question is that of how to display the state of the ship to the operators. Aside from the obvious indications like ship's pitch angle, depth, and control surface positions what else would be useful? Candidates include the net force acting on the ship, accelerations, and various time averaged values. Implied in this is that a nontraditional means of display will be used to show these parameters, so that the operators will not have to rely on a number of gauges or meters, with averaging of results only available only by the calibrated eye.

An intelligent assistant to the ship's control party would show items of current concern, and issue alerts based on an operator programmable doctrine. Issues like mast exposure, ship's relationship to the bottom, and trim state could be shown in an intuitive, logical manner.

Current evolutions and other items relating to the tactical employment could be included as required.

AIM OF THIS STUDY

Although the ship's control party currently relies on a small number of indications, the ability to sense "by the seat of the pants" cannot be discounted. This thesis investigates required feedbacks for robust automatic depth control at periscope depth, and thus indirectly evaluates the additional indications to be added to an integrated display.

This approach assumes that the best ship's control parties already use system states for control which are not explicitly displayed.

THESIS OUTLINE

Chapter II contains the development of the deeply submerged submarine dynamics model. Chapter III gives the development and source of the wave forces used to simulate operations at periscope depth. In Chapter IV, optimization studies are performed for nine different cases of state feedback control. This gives a feeling for the quality of depth control achievable by the use of different levels of sensors. Chapter V explores the use of sliding mode control for periscope depth operations. In Chapter VI, current ships control technology is reviewed and an integrated display is proposed. Conclusions and recommendations are given in Chapter VII.